THE RELATION

BETWEEN

THE ATOMIC WEIGHTS.

OF

THE CHEMICAL ELEMENTS.

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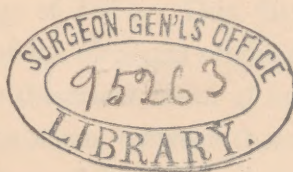ERVING PROFESSOR OF CHEMISTRY IN HARVARD UNIVERSITY.

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XI.

The Numerical Relation between the Atomic Weights, with some Thoughts on the Classification of the Chemical Elements.

By JOSIAH P. COOKE, Jr., A.M.,

ERVING PROFESSOR OF CHEMISTRY IN HARVARD UNIVERSITY.

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NUMERICAL relations between the atomic weights of the chemical elements have been very frequently noticed by chemists. One of the fullest expositions of these relations was that given by M. Dumas of Paris, before the British Association for the Advancement of Science, at the meeting of 1851. This distinguished chemist at that time pointed out the fact, that many of the elements might be grouped in triads, in which the atomic weight of one was the arithmetical mean of those of the other two. Thus the atomic weight of Bromine is the mean between those of Chlorine and Iodine; that of Selenium is the mean between those of Sulphur and Tellurium, and that of Sodium, the mean between those of Lithium and Potassium. M. Dumas also spoke of the remarkable analogies between the properties of the members of these triads, comparing them with similar analogies observed in Organic Chemistry, and drew, as is well known, from these facts arguments to support the hypothesis of the compound nature of many of the now received elements. Similar views to those of Dumas have been advanced by other chemists.

The doctrine of triads is, however, as I hope to be able to show in the present memoir, a partial view of this subject, since these triads are only parts of series similar in all respects to the series of homologues of Organic Chemistry, in which the differences between the atomic weights of the members is a multiple of some whole number. All the elements may be classified into six series, in each of which this number is

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different, and may be said to characterize its series. In the first it is nine, in the second eight, in the third six, in the fourth five, in the fifth four, and in the last three. The discovery of this simple numerical relation, which includes all others that have ever been noticed, was the result of a classification of the chemical elements made for the purpose of exhibiting their analogies in the lecture-room. A short notice of this classification will, therefore, make a natural introduction to the subject.

Every teacher of Chemistry must have felt the want of some system of classification like those which so greatly facilitate the acquisition of the natural-history sciences. In most elementary text-books on Chemistry, the elements are grouped together with little regard to their analogies. Oxygen, Hydrogen, and Nitrogen are usually placed first, and therefore together, although there are hardly to be found three elements more dissimilar; again, Phosphorus and Sulphur, which are not chemically allied, are frequently placed consecutively, while Arsenic, Antimony, and Bismuth, in spite of their close analogies with Phosphorus, are described in a different part of the book. This confusion, which arises in part from retaining the artificial classification of the elements into metals and metalloids, is a source of great difficulty to the learner, since it obliges him to retain in his memory a large number of apparently disconnected facts. In order to meet this difficulty, a classification of the elements into six groups, differing but slightly from that given in the table accompanying this memoir, was made. The object of the classification was simply to facilitate the acquisition of Chemistry, by bringing together such elements as were allied in their chemical relations considered collectively. As the classification has been in use for some time in the courses of lectures on Chemistry given in Harvard University, I have had an opportunity for observing its value in teaching, and cannot but feel that the object for which it was made has been in a great measure attained. The series which is headed The Six Series will illustrate the advantage gained from the classification in a course of lectures, the elements which compose it being among those especially dwelt upon in lectures to medical students, and, generally, very widely separated in a text-book on the science. As Chemistry is usually taught, the properties of the members of this series, Nitrogen, Phosphorus, Arsenic, and Antimony, as well as the composition and properties of their compounds, make up a large body of isolated facts, which, though without any assistance for his memory, the student is expected to retain. Certainly it cannot be wondered at, that he finds this a difficult task. The difficulty can, however, be in a great measure removed, if, after he has been taught that Nitrogen forms two important acids with Oxygen, NO_3 and NO_5, that it unites with Sulphur and Chlorine to form NS_3 and NCl_3, and also with three equivalents of Hydrogen to form NH_3, he is also

told, that, if in these symbols of the Nitrogen compounds he replaces N by P, As, or Sb, he will obtain symbols of similar compounds of Phosphorus, Arsenic, and Antimony; for he thus learns, once for all, the mode of combination of all four elements, so that when he comes to study the properties, in turn, of Phosphorus, Arsenic, and Antimony, he has not to learn with each an entirely new set of facts, but finds the same repeated with only a few variations. Moreover, these very variations he will learn to predict, if he is shown that the elements are arranged in the series according to the strength of their electro-negative properties, or, in other words, that their affinities for Oxygen, Chlorine, Sulphur, etc. increase, while those for Hydrogen decrease, as we descend. He will then readily see why it is that, though Nitrogen forms NO_3 and NO_5, it forms only NCl_3 and NS_3, and that this reason is correct he will be pleased to find confirmed when he learns that Phosphorus, which is more electro-positive than Nitrogen, and has, therefore, a stronger affinity both for Chlorine and Sulphur, forms not only PCl_3 and PS_3, but also PCl_5 and PS_5. Again, he will not be surprised, after seeing the affinity of the elements for Hydrogen growing constantly weaker as he descends in the series, to learn that a compound of Bismuth and Hydrogen is not certainly known. Should he inquire why, though NH_3 has basic properties, PH_3, AsH_3, and SbH_3 have not, he can be shown that the loss of basic properties in passing from NH_3 to PH_3 corresponds to a decrease in the strength of the affinity between the elements, and that if in PH_3, SbH_3, or AsH_3, atoms of Methyle, Ethyle, or other organic radicals analogous to Hydrogen, are substituted for the Hydrogen atoms, and more stable compounds thus obtained, strong bases are the result. The other series would afford similar illustrations, and, from my own experience, I am confident that no teacher who will once use the classification of the elements here proposed, or one similar to it, will ever think of attempting to teach Chemistry without its aid.

Classifications of the elements, more or less complete, have been given by many authors; but the fact that no one has been generally received, is sufficient to prove that they are all liable to objections, and would, indeed, also seem to show that a strictly scientific classification is hardly possible in the present state of the science. The difficulty with most of the classifications is, undoubtedly, that they are too one-sided, based upon one set of properties to the exclusion of others, and often on seeming, rather than real resemblances. This is the difficulty with the old classification into metals and metalloids, which separated Phosphorus and Arsenic, Sulphur and Selenium, because Arsenic and Selenium have a metallic lustre, while Phosphorus and Sulphur have not, though there could hardly be found another point of difference. For a zoölogist to separate the ostrich from the class of birds because it cannot fly,

would not be more absurd, than it is for a chemist to separate two essentially allied elements, because one has a metallic lustre and the other has not. Yet it is surprising to see how persistently this classification is retained in every elementary work on the science; and if it is sometimes so far modified as to transfer elements analogous to Selenium and Arsenic to the class of metalloids, this is only acknowledging the worthlessness of the principle, without being willing to abandon it. If there were any fundamental property common to all the elements, the law of whose variation was known, this might serve as the basis of a correct classification. Chemistry, however, does not as yet present us with such a property, and we must, therefore, here, as in other sciences, base our classification on general analogies. The most fundamental of all chemical properties is, undoubtedly, crystalline form, but a classification of the elements based solely on the principles of isomorphism is defective in the same way as it is in mineralogy. It brings together, undoubtedly, allied elements, but it also groups with them those which resemble each other only in their crystalline form. The mode of combining seems to be also a fundamental property; but, like crystalline form, it would bring together in some instances elements differing very widely in their chemical properties. A classification of the elements which shall exhibit their natural affinities, must obviously pay regard to both of these properties. It must at the same time seek to group together isomorphous elements, and those which form analogous compounds. Moreover, in such a classification, other less fundamental properties must not be disregarded. There are many properties both physical and chemical, which, although they cannot be exactly measured, and are oftentimes difficult to define, (such properties as those by which a chemist recognizes a familiar substance, or a mineralogist a familiar mineral,) and which on account of their indefinite character cannot be used as a basis of classification, may, nevertheless, render important aid in tracing out analogies. Judging from such properties as these, chemists are generally agreed in grouping together Carbon, Boron, and Silicon, although they cannot be proved to be isomorphous, and are not generally thought to form similar compounds.

It is, however, much easier to point out what a classification should be, than to make one which shall fulfil the required conditions. Indeed, as has been already said, past experience would seem to show that a perfect scientific classification of the elements is hardly possible in the present state of Chemistry. At best, the task is attended with great difficulties, and it cannot be expected that these should be surmounted at once. The classification which is offered in this memoir will, undoubtedly, be found to contain many defects. If, however, it is but one step in advance of those

which have preceded it, it will be of value to the science. It was originally made, as has already been said, simply for the purpose of teaching, and never would have been published had it not led to the discovery of the numerical relation between the atomic weights.

On turning to the table which accompanies this memoir, it will be seen that the elements have been grouped into six series. These correspond entirely to the series of homologues of Organic Chemistry. In the group of volatile acids homologues of Formic Acid, for example, we have a series of compounds yielding similar derivatives, and producing similar reactions, and many of whose properties, such as boiling and melting points, specific gravity, etc., vary as we descend in the series according to a determinate law. From Formic Acid, a highly limpid, volatile, and corrosive fluid, the acids become less and less volatile, less and less fluid, less and less corrosive; first oily, then fat-like, and finally hard, brittle solids, like wax. As is well known, the composition of these acids varies in the same way, and the variation follows a regular law, so that by means of a general symbol we can express the composition of the class. This symbol for the volatile acids may be written $(C_2H)O_3$, $HO + n(C_2H_2)$.

This description of the well-known series of the volatile acids, applies, word for word, *nominibus mutantis*, to each of the six series of chemical elements. The elements of any one series form similar compounds and produce similar reactions; moreover, they resemble each other in another respect in which the members of the organic series do not. Their crystalline forms are the same, or, in other words, they are isomorphous. Although this may be true of the volatile acids, yet it cannot be proved in the present state of our knowledge. Still further, many of their properties vary in a regular manner as we descend in the series. In one case, at least, the law of the variation is known, and can be expressed algebraically, though in most instances it cannot be determined. Finally, as one general symbol will express the composition of a whole organic series, so a simple algebraic formula will express the atomic weight, or, if you may be pleased so to term it, the constitution of a series of elements.

These points may be illustrated with any of the series in the table; with the first, for example, which consists of Oxygen, Fluorine, Cyanogen, Chlorine, Bromine, and Iodine. All these elements form similar compounds, as will be seen by inspecting the symbols of their compounds given at the right hand of the list of names, where the similar or homologous compounds are arranged in upright columns. Moreover, they are all isomorphous, as may be seen by referring to the left hand side of the list, where the similar compounds in each upright series are isomorphous, the numbers at the heads of the columns indicating the systems of crystallization, as is described in

the explanation accompanying the table. That the properties of these elements vary as we descend, can be easily shown. Oxygen is a permanent gas, as is also Fluorine. Cyanogen is a gas, but may be condensed to a liquid. Chlorine, a gas also, can be condensed more easily than Cyanogen. Bromine is a fluid at the ordinary temperature; and, finally, Iodine is a solid. Moreover, starting from Cyanogen, the solubility of these elements in water decreases as we descend in the series; and, again, the specific gravity of their vapors follows the inverse order of progression, gradually increasing from Oxygen down. The atomic weights vary in the same order, and admit of a general expression, which is $8 + n\,9$, or, in other words, the differences between the atomic weights of these elements are always a multiple of nine. This general formula may be said to represent the constitution of these elements, in the same way that the symbol $(C_2H)\,O_3$, $HO + n\,(C_2H_2)$ represents the composition of the volatile acids before mentioned. In the place of $(C_2H)\,O_3$, HO we have $8 = O =$ the weight of one atom of Oxygen, and in the place of C_2H_2 we have nine. What it is that weighs nine (for it must be remembered that those numbers are weights) we cannot at present say, but it is not impossible that this will be hereafter discovered. In order to bring the general symbol of the volatile acids into exact comparison with that of the Nine Series, we must reduce the symbols to weights, when the two formulæ become

$$46 + n\,14, \qquad \text{where } 46 = (C_2H)\,O_3, HO \qquad \text{and } 14 = C_2H_2;$$
$$\text{and } 8 + n\,9, \qquad \text{where } 8 = O \qquad\qquad\qquad \text{and } 9 = x.$$

The numbers 46 and 14 are known to represent the weights of aggregations of atoms. The number 8 represents the weight of one Oxygen atom, but we cannot as yet say what the 9 represents. After this comparison, it does not seem bold theorizing to suppose that the atoms of the members of this series are formed of an atom of Oxygen as a nucleus, to which have been added one or more groups of atoms, the weight of which equals nine, or perhaps one or more single atoms each weighing nine, to which the corresponding element has not yet been discovered. As it will be convenient to have names to denote the two terms of the formulæ which represent the constitution of the different series, we will call the first term, in accordance with this theory, the nucleus, and the number in the second term multiplied by n the common difference of the series.

From what has been said, it will be seen that the idea of the classification is that of the organic series. It is in this that the classification differs from those which have preceded it. Other authors, in grouping together the elements according to the principles of isomorphism, have obtained groups very similar to those here presented.

Indeed, this could not be otherwise, since, as has been already said, the members of each series are isomorphous, while, as a general rule, to which, however, there are many exceptions, no isomorphism can be established between members of different series. These groups, however, have been merely groups of isomorphous elements, and not series of homologues like those in which the elements are here classed.

These general remarks will suffice to indicate the principles upon which the classification has been made, and the character of the numerical relation between the atomic weights which has been established. The details of the classification can be best studied by referring to the table, so that it will be only necessary to speak of those points which are of special interest, or which may require explanation, or in regard to which there may be doubt. The series I have named from their common differences. The first I have called the Nine Series, the second the Eight Series, &c. Let us examine the doubtful points in each, commencing with the first.

The last five members of the Eight Series are connected by so many analogies, that they have been invariably grouped together in the elementary books. There can be no doubt, therefore, in regard to the propriety of placing them in the same series, on the ground of general analogies. Fluorine, it is true, presents some striking points of difference from the rest. Fluoride of Calcium is almost insoluble in water, while the Chloride, Bromide, and Iodide of Calcium are all very soluble. We must, however, remember that we have to do with series, and must not therefore expect to find close resemblances except between adjacent members. If, then, we consider that Oxygen is one of the series, and that Fluorine stands but one step removed from Oxygen, while it is two steps removed from Chlorine, the discrepancy in a measure vanishes, for Lime CaO is but slightly soluble in water. Nevertheless, the difficulty does not entirely disappear, for CaFl is much less soluble than CaO, although it should be more soluble judging from the law of the series and the fact that CaCl is so much more soluble than CaFl.

The solubility of a series of homologous elements or compounds in water, may be regarded as a function of one or more variables. In the case of elements there may be but one variable, but it is easy to see that in the case of compounds there must be several. One of these variables is probably the same which determines the common difference of the series to which the elements or compounds belong; (it will be hereafter shown that the atomic weights of the homologous compounds are related in the same way as those of the elements;) the other variables are perhaps the atomic forces which determine the hardness, density, &c. of the solid. We may, therefore, with justice, compare the relative solubilities of a series of homologues to a curve

which should be the same function of the same variables, and what mathematics
teaches we ought reasonably to expect in the case of this curve, we ought to expect
also in the variations of solubility of these substances. Now every mathematician
is familiar with the remarkably rapid changes which a curve undergoes that is a
function of several variables, and we cannot be surprised that similarly rapid changes
should be observed in the solubility of homologous substances in passing from one to
the next in the series. In the curve which corresponds to the relative solubility of CaO,
CaFl, CaCy, CaCl, CaBr, and CaI, it would seem that at CaFl there is a singular point
where the curve, after rising for some distance above the axis, bends down again
towards it. Several of the other series of compounds of these elements present sim-
ilar anomalies; for example, KO, KFl, KCy, KCl, KBr, and KI. Here the solubility
diminishes until we come to KCl, which is less soluble than KCy; then it increases
to the last. Here, of course, the singular point is at KCl. With the corresponding
compounds of Sodium, the solubility diminishes to NaFl, which is the least soluble of
the series, and then increases constantly to the end.

These facts at least seem to show that apparent variations from the law of series
in properties, which evidently are unknown functions of several variables, should not
be allowed to outweigh strong analogies, and certainly the analogies between Fluorine
and the other haloids are very marked. Fluorine itself possesses properties such as
we should expect to find in a member of the series above Chlorine. The strong and
active affinities of Fluorine might be indeed predicted, after seeing the rapid increase
both in the strength and activity of the affinities in passing from Iodine to Chlorine.
In passing from Bromine to Chlorine, we pass from a liquid to a gas, permanent under
any natural conditions; and we should expect, therefore, in rising still higher in the
series, to find in Fluorine a gas less easily reduced to a liquid than Chlorine. Now
although, on account of its remarkably active affinities, this fact cannot be demon-
strated on the gas itself; it can, nevertheless, be inferred with perfect certainty from
its compounds. Finally, the isomorphism of Fluorine and the other haloids may be
urged as indicating close analogy. From these considerations, I cannot but think that
those chemists who have questioned the propriety of classing Fluorine with the other
haloids will, on reviewing the facts, and regarding the haloids in the light of a series,
and not simply as a group of elements possessing certain general properties, be led
to change their opinion.

Cyanogen, though a compound radical, has been classed with the other haloids, not
only from its atomic weight, but also from its other analogies. Its properties are in
most cases those which we should expect from an element occupying its position in

the series; but in others it presents remarkable variations, owing probably to the fact that it contains a radical which is easily decomposed. As well known, it is perfectly isomorphous with Chlorine.

The propriety of classing Oxygen in this series seems to be placed beyond doubt by the discovery of Ozone, which, though it does not seem to possess such energy as we should expect in an element higher in the series than Fluorine, may, nevertheless, be found to fulfil all anticipations should it ever be obtained in a perfectly unmixed condition. The isomorphism of Oxygen with Chlorine, and therefore with the other haloids, seems sufficiently established by the determination both of Proust and Misterlich of the tetrahedral form of Cu_2Cl. It must, however, be admitted that Oxygen presents as strong analogies with Sulphur as it does with Chlorine; and since, not only from its analogies, but also from its atomic weight, it appears to be the nucleus in all the first three series, I have placed it at the head of each. It may be mentioned here, that in all cases the fact that the atomic weight of an element is included in the general formula of a series, is an argument for classifying it in that series, if the relation between the atomic weights pointed out in this memoir is admitted to be a law of nature; but as I wish to show that the relation is not that of a mere accidental group of numbers, but is connected with the most fundamental properties of the elements, and has, therefore, the claims of a law, I have endeavored to establish the correctness of the classification which conforms to the law, and, indeed, suggested the law on other grounds.

The atomic weights of the numbers of the Nine Series, as determined by experiment, present greater deviations from the numerical law already explained, than are to be found in any of the others. The weights which would exactly conform to the general formula $8 + n9$ are given in the column of the table headed Theoretical, while in the next column at the right are given the weights of experiment. These for the most part (in this as well as in the other series) have been taken from the table of Atomic Weights given in the last volume of Liebig and Kopp's *Jahresbericht* (for 1852), which was supposed to give the most accurate and latest results. In the few cases in which the numbers have not been taken from this table, the initial letter of the name of the observer has been annexed. It will be seen, on comparing the two columns that the greatest deviation from the law is in the case of Fluorine, if we consider the care which was taken both by Berzelius and Louyet in the determination of the atomic weight of this element. It may, however, be remarked, that, as the processes used by both experimenters were essentially identical, any hidden constant source of error would produce the same effect on both results; so that the atomic weight of Fluorine cannot be regarded as yet as absolutely fixed. Nevertheless, it is not possible that so

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great a difference between the true and observed weights as two units could have escaped detection in the numberless analyses which have been made, by the most experienced chemists, of the Fluorine compounds. It must, therefore, be admitted, and not only in the case of Fluorine, but also in other instances, that there are deviations from the law; but these deviations are not greater than those from similar numerical laws in astronomy and other sciences, and indeed, judging from the analogy of these sciences, ought to be expected.

Those who are not familiar with the amounts of probable error in the determination of the different atomic weights would judge, on comparing together the columns of theoretical and observed values, that the deviations from the law were much greater than they are in reality. It should, therefore, be stated, that, in by far the larger number of instances, the deviations are within the limit of possible errors in the determinations, leaving only a few exceptional cases to be accounted for. It must be remembered that, other things being equal, the amount of probable error is the greater the greater the atomic weight, so that a difference of 1.9 in the case of Iodine is not a greater actual deviation from the law than only 0.5 in the case of Chlorine. Indeed, it is very possible that on more accurate determinations the atomic weight of Iodine will be found to correspond to the law, which cannot be expected of that of Chlorine. It is well known that many of the larger atomic weights, especially those of the rarer elements, cannot be regarded as fixed within several units.

I have calculated, as well as the data I have would permit, the amount of probable error in the determinations of many of the atomic weights, and by comparing together the results from different processes, and by different experimenters, I have endeavored to detect the existence of constant errors, which seem to be the great errors in all these determinations, those accidental errors which are made in the repetitions of the same process by equally careful experimenters being comparatively insignificant. The results of this investigation will be published in a subsequent memoir. It is sufficient for the present purpose to state, that, while they show that, in the greater number of cases, the apparent variations from the law are within the limit of probable error, there are yet several instances, where, after allowing for all possible errors of observation, there is a residual difference. I do not therefore look alone to more accurate observations for a confirmation of the law, but, regarding the variations as ascertained facts, hope that future discovery will reveal the cause. Whether the variations will be found to be a secondary result of the very cause which has determined the distribution of the atomic weights according to a numerical law, as the perturbations in astronomy are a necessary consequence of the very law they seemed at first to invalidate, or

whether they are due to independent causes, can of course, for the present, be only a matter of speculation. There are, however, facts which seem to indicate that the variations are not matters of chance, but correspond to variations in the properties of the elements.

From the beautiful discovery of Professor Schönbein we have learnt that Oxygen has two allotropic modifications, and that besides its ordinary condition it is capable of assuming another highly active state when its properties resemble those of Chlorine. Cyanogen is only known in a quiescent state. The other haloids, Fluorine, Chlorine, Bromine, and Iodine are only known in a highly active state. Now it will be seen on examining the table, that the atomic weights of the highly active elements, as determined by experiment, exceed slightly the theoretical numbers, and that where the affinities are the most intense, in Fluorine, the deviation is the greatest. A similar fact may be observed in the atomic weights of the members of the Six Series. Arsenic has been proved to be capable of existing in two allotropic modifications. In its ordinary state, it has a crystalline form belonging to the Rhombic System. In the other condition, in which it may be obtained by sublimation at a low temperature, it crystallizes in regular octahedrons. The other members of this series are probably isodimorphs with Arsenic. The ordinary condition of Phosphorus is its monometric modification, while the rhombic state seems to be the normal condition of Arsenic, Antimony, and Bismuth. Now the atomic weights of the last three are either equal to, or slightly exceed, the theoretical number, while that of the first fall short, perhaps even by a unit. Other facts, which also tend to show that the deviations are not matters of chance, may be found in the affiliations of the series. There are some elements which seem to be most remarkably double-faced, having certain properties which connect them closely with one series, and at the same time others which unite them nearly as closely to another. In such cases we find that the atomic weight either falls naturally into both series, or, not corresponding exactly with the theoretical number of the series to which the element properly belongs, it inclines towards that of the other, and sometimes equals it. Such is the case with Chromium, Manganese, and Gold, as will be seen by referring to the affiliations at the bottom of the Nine Series. These various facts force upon me the conviction, that this relation between the atomic weights is not a matter of chance, but that it was a part of the grand plan of the Framer of the universe, and that in the very deviations from the law, there will, hereafter, be found fresh evidence of the wisdom and forethought of its Divine Author.

The general formulæ for the Eight Series are $8 + n8$ and $4 + n8$. The two nuclei correspond to two different sets of elements, or sub-series, one consisting of Oxygen,

Sulphur, Selenium, and Tellurium, the other of Molybdenum, Vanadium, Tungsten, and Tantalum. The atomic weights of the first are all equal to $8 + n8$; those of the second to $4 + n8$. The sub-series exhibit marked analogies, as well as certain differences. They resemble each other chiefly in that the members of both form analogous acids with Oxygen, while they differ in that, though the members of the first sub-series form compounds with Hydrogen, those of the second do not. The isomorphism of the members of each sub-series among themselves, with the exception of Vanadium, is complete; but there seems to be no proof of any isomorphism between the sub-series. Johnston attempted to establish the isomorphism of Chromic and Molybdic Acids from the red variety of Molybdate of Lead from Rezbanya, which he supposed to be a Chromate; but the fact has been disproved by G. Rose, who has shown that the supposed Chromate is a Molybdate mixed with a small amount only of Chromate. There seems, nevertheless, to be some reason for believing that Chromic Acid may replace Molybdic Acid to a certain extent. If this is proved, it establishes another link of connection between the members of the two sub-series, since Chromic Acid is isomorphous with Sulphuric Acid. For the present, however, we must regard them as sub-series, related, but distinct, the second being in a measure supplementary to the first. They are distinguished in the table by printing the names of the second sub-series a little to the right of those of the first, and the fact that their atomic weights are intermediate to those of the first, I have indicated to the eye by giving to the names also an intermediate position.

The analogies between Oxygen and Sulphur are so numerous, that, were we to place Oxygen in but one series, we should place it in this. HO and HS, HO_2 and HS_2, resemble each other very closely, as do also the Oxygen salts the corresponding Sulphur salts. Moreover, there can be no doubt in regard to the isomorphism of the two elements, since it has been established upon the authority both of Mitscherlich and Becquerel, and from two different compounds. The only doubtful case in the series was that of Vanadium, which in some of its properties resembles Arsenic more closely than it does Molybdenum. The reasons for giving it the place which it occupies were the facts that its acids correspond to those of Molybdenum, and that it forms remarkably highly colored oxides which are repeated also in Molybdenum. It is true that the properties of the element itself are not those we should expect from the position which it occupies in our table; yet, if it were placed in the Six Series, it would fall between Phosphorus and Arsenic, which on the whole it resembles less than it does Molybdenum, for although it is combustible, yet neither it nor its oxides are volatile. I consider it, therefore, as a member of the Eight Series, but affiliating very closely with the Six. Its

atomic weight favors this hypothesis. Vanadate of Lead has been considered isomorphous with the Phosphate; but as this isomorphism does not rest on any measurement of angles, and as, moreover, the received symbols of the two minerals, Vandinite and Pyromorphite, on whose crystalline forms the isomorphism was determined, show a very different constitution, I have not given much weight to this fact.* The observed atomic weights of the members of this series are almost precisely the same as the theoretical members, and, with the exception, perhaps, of Molybdenum, there appears to be no instance in which the difference is greater than the amount of possible error.

The members of the Six Group form a well-characterized family, so that, with the exception of Oxygen, there can be no doubt in regard to the justice of classifying them together, and any discrepancies will disappear on considering the group in the light of a series. They form acids containing three and five atoms of Oxygen which are completely homologous, and make two series parallel to that of the elements. They form also a remarkable series of compounds with three atoms of Hydrogen. The idea which has been advanced by some authors, that NH_3 is the Nitride of Hydrogen, while PH_3 is the Hyduret of Phosphorus, or, in other words, that Hydrogen is electro-positive with reference to Nitrogen and electro-negative with reference to Phosphorus and those lower in the series, does not seem to me correct, since the remarkable bases which may be formed from PH_3, AsH_3, SbH_3, and BiH_3, by replacing the Hydrogen atoms by organic radicals, seem to indicate that they have the same type as NH_3, and are therefore homologues of it.

The isomorphism of the four lower members of the series is perfect. It has been shown in the table, both by the crystalline forms of the elements themselves, as well as by those of their coumpounds. In the other series, wherever it was possible, the same double proof has been given. The doubt expressed by G. Rose in regard to the dimorphism of Arsenic, as I hope to be able to show in a paper soon to be published, has been removed. In one state Arsenic crystallizes in perfect octahedrons of the regular system, and is therefore isomorphous, not only with Antimony and Bismuth, but also, in its allotropic state, with Phosphorus. Isomorphism, as is well known, is not absolute, except in forms of the regular system. The rhombic angles of the crystals of Arsenic, Antimony, and Bismuth are respectively 85° 41', 87° 35', 87° 40', and therefore conform to the general rule. It will be observed that the angle varies constantly in the same way as we descend in the series. Now, although these few instances do not afford sufficient ground for any general conclusion, yet they show that similar varia-

* See G. Rose's Mineral System.

tions are possible in the other systems, and therefore that we cannot be expected to establish isomorphism in any case except between nearly consecutive members.

The atomic weights of the members of this series, with the exception of Phosphorus, do not present any important deviations from the theoretical numbers, taking into account always, of course, the amount of possible error. The deviation in the case of Phosphorus has already been noticed. Oxygen, it must be admitted, is not connected with the series from any similarity of properties, though the Phosphides, Arsenides, and Antimonides present certain analogies with the Oxides. As has already been said, Oxygen was placed at the head of this, as well as of the last two series, because its atomic weight seemed to be the nucleus of all three.

The Five Series is the shortest of all, consisting of only three members, Carbon, Boron, and Silicon. Of these, the last two are as closely allied as are any two members of the other series, Silicon having precisely the properties we should expect in a homologue of Boron, which was lower in the series; and the same is also true of their compounds. The analogies, however, between these two elements and Carbon are by no means so close, for not only Carbon cannot be proved to be isomorphous with them, but it does not form similar compounds. Carbonic Acid, it is true, presents some points of resemblance to Boracic and Silicic Acids; like them it unites in a large variety of proportions with bases, its alkaline salts give a basic reaction, &c.; but according to the generally received opinion, its symbol is CO_2, while those of Boron and Silicon are BO_3 and SiO_3. In its uncombined state, however, Carbon resembles Boron and Silicon, not only in its outward properties, but also in its action before the blowpipe. Two of the allotropic states of Carbon, Graphite and Charcoal, are probably repeated in Boron, and are known to be in Silicon. The principle of exclusion would also seem to place Carbon in this series, for it certainly presents no analogies with the members of any other. The correspondence of the atomic weights of the members of this series to the law is remarkably close.

The Four Series is by far the largest of all, including the greater number of what are generally known as the heavy metals. The members of the series resemble each other in the following respects. First, they are isomorphous; for although each member cannot be directly proved to be isomorphous with every other, yet isomorphism can be established between consecutive members, which, as has before been said, is all that can be expected. Second, the members of this series all form, by uniting with Oxygen, either Protoxides or Sesquioxides, or both, which, as a general rule, are strong bases. Third, these Oxides are either insoluble, or nearly insoluble, in water. And finally, the elements of the series have all those physical properties which are known as metallic properties.

This series may be naturally divided into two sub-series. The first contains those elements whose protoxide bases are their characteristic compounds, and which do not form acids with Oxygen. The second contains those elements whose characteristic compounds are their sesquibases. They generally unite with two or more equivalents of Oxygen, and form acids. These sub-series are distinguished in the table in the same way as those of the Six Series. Corresponding to these sub-series we have two sets of atomic weights, each having the same common difference, but differing in their starting-point or nucleus. The first set is expressed by the formula $4 + n4$, the second by $2 + n4$.

The sub-series affiliate with each other in a most remarkable manner. Manganese, for example, not only forms a strong protoxide base, but also unites with a larger amount of Oxygen, forming both a sesquibase and acids. Its atomic weight places it in the first group, and it has therefore been classed there, although by its properties it is equally allied to the second. Cobalt and Nickel certainly resemble much more closely the members of the first than of the second sub-series, although their atomic weights place them in the second. With this exception, the subdivision of the series which the atomic weights require does not differ from that suggested by the properties of the elements. The members of this series may of course be still further subdivided into groups according to their special properties, as they are in all works on Chemistry. They are placed together here because the atomic weights form but one numerical series.

The isomorphism of the members of this series will be found well established with the limitations before given. In order to establish the isomorphism of Cobalt and Nickel with Iron, the isomorphism of one atom of Arsenic with two atoms of Sulphur has been assumed. This is generally admitted; but if it is not, no one can doubt in regard to the isomorphism of these three metals, as they constantly replace each other. Glucinum, Zirconium, Lanthanum, Cerium, and Thorium cannot be shown to be isomorphous with the other metals by any of their compounds, but their oxides are known to replace the analogous oxides of the other metals. So also is Ruthenium known to replace Rhodium. There have been doubts expressed in regard to the existence of a monometric form of Zinc; but as we have established its isomorphism with the other members of the series, not only by its own crystalline form, but also by those of its compounds, the fact is of no importance to the present question.

The atomic weights of the members of this series, as determined by observation, very nearly correspond with the theoretical numbers, which is the more remarkable, as the limit of error in the determination of the atomic weights of the greater number, especially of the rarer metals, is quite wide.

The Three (and last) Series is composed of Hydrogen and the metals of the alkalies. The analogies between Lithium, Sodium, and Potassium are very close, as is well known, and there can be no doubt in regard to the propriety of classing them together. It may be said, however, in regard to Hydrogen, that it resembles as closely some of the metals of the Four Series as it does those of the alkalies. Though this cannot be denied, yet the fact that the atomic weight of Hydrogen is the nucleus of the series, and the great solubility of the alkalies in water, may be urged as reasons for placing it at the head of the Three Series.

The isomorphism of Lithium, Sodium, and Potassium is fully established; but I can find no data which prove Hydrogen isomorphous either with them or with the metals of the other group.

The unit of the atomic weights which has been used thus far throughout the table, is the double atom of Hydrogen; but the nucleus of the Three Series is the weight of the single atom, so that the unit in this series is one half of the unit of the weights in all the other series. This fact must be kept in mind in comparing the atomic weights of this with those of the other series. All the weights might have been made uniform by doubling them throughout; but as this would not have changed the relation, and would have been departing from the general custom, it was thought best to confine the doubling to the Three Series, into which alone Hydrogen enters. The general symbol of this series is $1 + n\,3$, where of course the unit is one half of that of the symbols at the head of the other series. The observed atomic weights will be found to correspond very closely with the theoretical numbers; indeed, the two coincide, except in the case of Potassium, where the difference is 0.6. This, however, it must be remembered, is 0.6 of the single Hydrogen atom. Compared with the double atom, as the weight of Potassium is generally given, the difference amounts to but 0.3.

One of the most remarkable points of the classification which has been now explained, is the affiliation of the series. We find in Chemistry, as in other sciences, that Nature seems to abhor abrupt transitions, and shades off her bounding lines. Many of the elements, while they manifestly belong to one series, have properties which ally them to another. Several examples of this have already been noticed. In such cases, we find invariably that there is a similar affiliation of the atomic weight. Of all the elements Chromium and Manganese are the most protean. Two atoms of these elements unite with seven atoms of Oxygen and form acids analogous to Perchloric Acid, and, as has already been shown, the weight of two atoms of either element falls into the Nine Series. Moreover, one atom of Chromium or of Manganese unites with three atoms of Oxygen to form Chromic or Manganic Acid. Chromic Acid is a

strong oxidizing agent, and resembles closely Nitrous Acid, and the atomic weight of Chromium falls into the Six Series just below that of Nitrogen. Manganic Acid, on the other hand, resembles Sulphuric Acid, with which it is isomorphous, and the atomic weight of Manganese would place it in the Eight Series. In like manner Osmium in many of its properties resembles Platinum and the other metals with which it is associated in nature; but, unlike them, it forms a very remarkable volatile acid, whose insupportable and suffocating odor as well as composition reminds one of the acids of the Nine Series, and its atomic weight seems to justify the apparent analogy. Gold likewise, though the noblest of metals, yet in some of its chemical relations resembles much more closely the members of the Nine than of the Four Series, and here again its accommodating atomic weight seems to account for its double-sided character. Several other examples of similar affiliations are given in the Table, but do not need explanation.

In the description just concluded of the classification of the chemical elements, which is offered in this memoir, I have not entered into details, for to have done so would have been to write a treatise on Chemistry. I have confined myself almost exclusively to general points, and only referred to those particulars which I thought might present doubts. I hope that I have been able to show, first, that the chemical elements may be classified in a few series similar to the series of homologues of Organic Chemistry; second, that in those series the properties of the elements follow a law of progression; and finally, that the atomic weights vary according to a similar law, which may be expressed by a simple algebraic formula. As already intimated, I have endeavored to prove the correctness of the classification on general grounds, in order that it might appear that the simple numerical relation which has been discovered between the atomic weights is not a matter of chance, but is connected with the most fundamental properties of the elements. I might leave the subject at this point, but the existence of the law which I wish to establish will be proved more conclusively if it can be shown, not simply that the general properties of the members of each series vary in a regular manner, but also if in one or more cases the exact law of the variation can be pointed out.

There are but few properties of the elements which are subjects of measurement, and which therefore can be compared numerically. Such are the specific gravity in the three states of aggregation, the boiling and melting points, the capacity of heat, and a few others. It is easy to see that there are but few of these properties the law of whose variation in the series we could reasonably expect to discover in the present state of science. Most of them evidently depend upon molecular forces with which

we are entirely unacquainted. Such in solids is undoubtedly the case with so simple and fundamental a property as specific gravity, and most, if not all, of the other properties of solids belong to the same category. It cannot therefore be expected that we should point out the laws by which these properties vary, although the remarkable investigations of Dana, Filhol, Kopp, Schröder, and others, on the relations between the density of substances and their atomic weights, and those of Kengott on the relation of hardness to atomic volume, give grounds for expecting that even they will before long be discovered. In liquids and gases, however, most of these molecular forces which produce the apparent irregularities in solids have less influence, as we should naturally expect, probably because the atoms are removed out of the sphere of their action. We may therefore hope, on comparing together the properties of the liquid or gaseous states of the elements in any series, to discover some numerical relation between them. Unfortunately, however, we have not sufficient data for making such a comparison except in the case of one property, the specific gravity. The boiling point, which would be a very valuable property for the purpose, is known only in a few instances.

That the specific gravity of the elements in their gaseous state varies in each series according to a numerical law, follows necessarily from what is already known. It is a well-known fact, that the specific gravities of the gaseous states of the elements divided by their atomic weights give quotients which are either equal, or which stand in a very simple relation to each other. For any series, as far as we have data, this quotient is the same for all the elements with only a few exceptions. That is $\frac{\text{Sp. Gr.}}{\text{At. W.}} = p$. But we have found that At. W. may be expressed in general by $a + n b$, and substituting this for At. W. in the above equation, it becomes $\frac{\text{Sp. Gr.}}{a + n b} = p$, or Sp. Gr. $= p a + n p b$; so that $p a + n p b$ is a general expression for the specific gravity of all the elements of any series, in the same way that $a + n b$ is for the atomic weight. The value of p will differ according as the specific gravities used are referred to Hydrogen or Air. Below will be found tables which give the calculated and observed specific gravities of the elements of the Nine and Six Series referred to Hydrogen, which has been taken as the unit instead of Air, as we thus in great measure avoid fractions. In the Nine Series $p = 1$, so that the numbers representing the specific gravities are the same as those representing the atomic weights. In the Six Series it equals two, so that the numbers representing the specific gravities are in this series twice as large as those representing the atomic weights. When the specific gravity has not been observed, the calculated number only is given. The observed numbers are taken from the " Table of Specific Gravity of Gases and Vapors," in Graham's *Elements of Chemistry*, which is a very complete collection of all known data. For the other series, we have only occasional data, so that no complete tables of their specific gravities are possible.

THE NINE SERIES. $\dfrac{\text{Sp. Gr.}}{\text{At. W.}} = 1.$ Sp. Gr. $= 8 + n\,9.$			THE SIX SERIES. $\dfrac{\text{Sp. Gr.}}{\text{At. W.}} = 2.$ Sp. Gr. $= 16 + n\,12.$		
Names.	SPECIFIC GRAVITIES.		Names.	SPECIFIC GRAVITIES.	
	Theoret.	Observed.		Theoret.	Observed.
Oxygen	8	16	Oxygen	16	16
Fluorine	17		Nitrogen	28	14
Cyanogen	26	26	Phosphorus	64	64
Chlorine	35	35.5	Arsenic	148	150
Bromine	80	78	Antimony	256	
Iodine	125	126	Bismuth	412	

It is evident, then, that at least one property of the elements varies in the series according to an ascertained numerical law. But, it may be said, this proves nothing, for these specific gravities are connected so closely with the atomic weights that what is true of the one must be to the same extent true of the other. It must be remembered, however, that the specific gravities are a distinct set of observed facts, and that the probability of a law is in exact proportion to the number of facts which accord with it. Moreover, the closeness of the connection is unimportant. Whether the value of p be expressed by a single digit, or by a complicated algebraic formula, is evidently a matter of indifference so far as the confirmation of the law is concerned.

I regret exceedingly that there are not sufficient data in the case of any of the other properties of the elements in the state of gas to allow comparison, as I feel confident that the law which governs their variation in the series might easily be discovered; but I look forward to the time when in the general formula $p\,a + n\,p\,b$ the value of p shall be known, not only for the properties of the elements in their gaseous state, but for every property capable of numerical expression.

In this memoir I have confined myself entirely to the elements, but it is evident

that the classification here offered, and the numerical law here explained, may be extended to all compounds. The elements of any one series, by combining, give rise to perfectly parallel series of homologous binaries, some of which are given in the table. The binaries of those series which have the greatest common difference are generally acids; and of those which have the smallest, they are generally bases. These acids and bases unite together and form series of homologous salts. As in Organic Chemistry, many of the series are very incomplete; but they are much more generally perfect than in that newer department of the science, and almost every day fills up some gap.

It will be seen, then, that not merely a plan has been given for classifying the elements, but one which will also embrace all inorganic compounds, and affiliate with the similar classification which has already been established in Organic Chemistry. We have not attempted to develop such a classification, since to do it would require a volume; nor is it necessary, as any one can develop it for himself.

That the atomic weights of the series of homologous compounds follow the same numerical law as those of the elements is easily shown. Take as an example the series of salts homologous with KO, NO_5, which may be expressed in general by KO, RO_5, where R is any member of the Six Series after Oxygen, and whose atomic weight, therefore, equals $8 + n\,6$. The atomic weight of KO, RO_5 must be necessarily $39.5 + 48 + (8 + n\,6)$, or $95.5 + n\,6$. As this symbol differs from that of the Six Series only in the nucleus, the atomic weights of the salts which are represented by it must progress by the same differences as those of the corresponding elements.

The properties of these series of homologous compounds will also be found to vary in a regular manner, and the law of the progression of the specific gravities in the gaseous state can be easily expressed algebraically, since in each series the quotient of the specific gravity divided by the atomic weight is a constant quantity. As an illustration, we may take the series of binaries homologues of water given in the Nine Series of our table. It follows from what has been said, that the atomic weights of these compounds equals $9 + n\,9$. With each $\frac{\text{Sp. Gr.}}{9 + n\,9} = \frac{1}{2}$, therefore Sp. Gr. $= 4.5 + n\,4.5$. We give below a table of the observed or calculated specific gravities, not only of these compounds, but also of those homologues of NH_3 whose specific gravity has been observed.

HOMOLOGUES OF WATER. $\frac{\text{Sp. Gr.}}{\text{At. W.}} = \frac{1}{2}.$ Sp. Gr. $= 4.5 + n\,4.5.$			HOMOLOGUES OF AMMONIA GAS. $\frac{\text{Sp. Gr.}}{\text{At. W.}} = \frac{1}{2}.$ Sp. Gr. $= 5.5 + n\,3.$		
Symbols.	SPECIFIC GRAVITIES.		Symbols.	SPECIFIC GRAVITIES.	
	Theoret.	Observed.		Theoret.	Observed.
HO	4.5	9	NH_3	8.5	8.5
HFl	9		PH_3	17.25	17.5
HCl	13.5	13.5	AsH_3	39	38.5
HBr	40.5	39.5			
HI	63	63.5			

As the series of compounds give a greater scope for investigating the relations of properties than is presented by those of the elements, we may expect that these relations will be first discovered in the former, and to my conceptions Chemistry will then have become a perfect science, when all substances have been classed in series of homologues, and when we can make a table which shall contain, not only every known substance, but also every possible one, and when by means of a few general formulæ we shall be able to express all the properties of matter, so that when the series of a substance and its place in its series are given, we shall be able to calculate, nay, predict, its properties with absolute certainty; and when our chemical treatises shall have been reduced to tables of homologues, and our laws comprised in a few algebraic formulæ, then the dreams of the ancient alchemist will be realized, for the problem of the transmutation of the elements will have been theoretically, if not practically, solved.

EXPLANATION OF THE TABLE.

THE formula at the head of each series is a general expression for the atomic weights of that series.   The names of the series are derived from the "Common Differences," which are the numbers multiplied by n in the general formulæ.   In the columns headed "Theoretical" are given the atomic weights calculated from these formulæ and the values of n given in the last columns at the right of each division of the table. In the columns headed "Observed" will be found the observed values of the same atomic weights.   These have been taken from the table of atomic weights given in the last volume of Liebig and Kopp's *Jahresbericht* (for 1852), with the exception of those against which are placed the initials of the observers.   The last were taken from Weber's *Atomgewichts Tabellen*.   In some cases the atomic weight is taken at twice its received values, but it is then underlined.   The compounds in any one column at the right of the names of the elements are homologous.   In the same way, those in any one at the left are isomorphous.   The numbers at the head of these last columns indicate crystalline systems as follows: 1. Monometric; 2. Dimetric; 3. Trimetric; 4. Monoclinic; 5. Triclinic; 6. Rhombic.   The data from which the table was compiled were drawn from numerous sources, but especially from the following works: Gmelin's *Handbook of Chemistry*, Graham's *Elements of Chemistry*, Phillips's *Mineralogy* by Brooke and Miller, and Gustav Rose's *Krystallo-chemische Mineralsystem*. References have been given only in a few cases, to avoid crowding the tables.   For authorities in other cases, the author would refer to the above-mentioned works.

THE NINE SERIES.

8 + n9.

ISOMORPHS.			HOMOLOGUES.							ATOMIC WEIGHTS.		
3		1								Theo.	Observed.	n
		*Cu₂O	Oxygen.	HO						8	8	n= 0
		KFl	Fluorine.	HFl						17	18.8B	n= 1
		KCy	Cyanogen.	HCy	CyO					26		n= 2
KO,ClO₇	*Ca₂Cl	KCl	Chlorine.	HCl	ClO	ClO₂	ClO₄	ClO₅	ClO₇	35	35.5	n= 3
		KBr	Bromine.	HBr	BrO†			BrO₅		80	80	n= 8
		KI	Iodine.	HI	IO		IO₂	IO₇		125	126.9M	n=13

AFFILIATIONS.

	KO,CrO₂		Chromium.					Cr₂O₇	53	55.4	n= 5
KO,Mn₂O₇	KO,MnO₂		Manganese.					Mn₅O₇	53	55.2	n= 5
			Osmium.			OsO₄			98	99.4	n=10
			Gold.		AuO₂		AuO₅†		197	197	n=21

* Mitscherlich J. pr. Chem. 19, 449.

THE EIGHT SERIES.

8 + n8 or 4 + n8.

ISOMORPHS.					HOMOLOGUES.					ATOMIC WEIGHTS.		
6	4	3	2	1						Theo.	Observed.	n
				†PbO *Cu₂O	Oxygen.	HO	HO₂			8	8	n= 0
	KO,SO₂	‡Fe₂S₄		PbS *Ca₂S	Sulphur.	HS	HS₂	SO₂	SO₃	16	16	n= 1
	KO,SeO₂			PbSe	Selenium.	HSe		SeO₂	SeO₃	40	39.6B	n= 4
			PbO,MoO₂		Molybdenum.			MoO₂	MoO₃	44	44	n= 5
Te				PbTe	Tellurium.	HTe		TeO₂	TeO₃	64	64.1B	n= 7
					Vanadium.			VₐO₂	VₐO₃	68	68.5B	n= 8
	FeO,WO₂		PbO,WO₂		Tungsten.			WO₂	WO₃	92	92	n=11
	FeO,TₐO₂				Tantalum.			TₐO₂	TₐO₃	188	184	n=23

AFFILIATIONS.

As		†Fe₃(AsS₃)			Arsenic.				148	150	n=18
	KO,MnO₂				Manganese.			MnO₄	28	27.6	n= 3

* Mitscherlich J. pr. Chem. 19, 449. † Becquerel Ann. Chem. Phys. 51, 105. ‡ G. Rose Krystallochemische Mineralsystem.

THE SIX SERIES.

8 + n6.

ISOMORPHS.			HOMOLOGUES.					ATOMIC WEIGHTS.		
6	3	1						Theo.	Observed.	n
			Oxygen.					8	8	n= 0
			Nitrogen.	*NH₂	NH₃	NO₂	NO₅	14	14	n= 1
	NaO,PO₂+4HO	P	Phosphorus.	PMo₃ PH₃ AsMe₂	PMe₂ PH₄	PO₂	PO₅	32	31	n= 4
As	NaO,AsO₂+4HO	As	Arsenic.	AsH₃ SbMe₂	AsO₂	AsO₅		74	75	n=11
Sb	SbS₂	SbO₅	Antimony.	SbH₂ BiAe₂	SbO₂	SbO₅		128	129	n=20
Bi	BiS₂		Bismuth.	BiH₂†	BiO₂	BiO₅		206	208	n=33

AFFILIATIONS.

			Chromium.		CrO₂	26	26.7	n= 3
			Vanadium.		VₐO₂	68	68.5	n=10

* Only known in combination.

THE FIVE SERIES.

6 + n5.

ISOMORPHS.		HOMOLOGUES.		ATOMIC WEIGHTS.		
6	1			Theo.	Observed.	n
	C	Carbon.	CO₂	6	6	n= 0
*BO₃		Boron.	BO₂	11	10.9	n= 1
*SiO₃		Silicon.	SiO₂	21	21.3	n= 3

AFFILIATIONS.

	Ti	Titanium.	TiO₂	26	25.2	n= 4

* Boracic Acid appears to replace Silicic Acid in Acmite and other minerals.

THE FOUR SERIES.

4 + n4 or 2 + n4.

ISOMORPHS.								HOMOLOGUES.							ATOMIC WEIGHTS.		
6	5	3	2	1											Theo.	Observed.	n
								Glucinum.	GlO						4	4.7	n= 0
MgO,CO₂				MgO,Al₂O₃			MgO	Magnesium.	MgO						12	12	n= 2
	Al₂O₃			ZnO,Al₂O₃				Aluminum.		Al₂O₃					14	13.7	n= 3
CaO,CO₂		CaO,CO₂						Calcium.	CaO		CaO₃				20	20	n= 4
	(TiFe)O₂ Cr₂O₃	TiO₂					Ti	Titanium. Chromium.	TiO CrO	Cr₂O₃	TiO₂ CrO₂	CrO₃	Cr₂O₇		26 26	25.2B 26.7	n= 6 n= 6
MnO,CO₂ FeO,CO₂	Fe₂O₃		FeO,Fe₂O₃	MnS₂ FeS, CoS₂+CoAs NiS₂+NiAs	MnS		Fe	Manganese. Iron.	MnO FeO	Mn₂O₃ Fe₂O₃	Mn₃O₄ Fe₃O₄	MnO₅	MnO₇ Mn₂O₇		28 28	27.6 28	n= 6 n= 6
				CoS₂+CoAs NiS₂+NiAs				Cobalt. Nickel.	CoO NiO	Co₂O₃ Ni₂O₃	Co₃O₄				30 30	29.5R 29.5R	n= 7 n= 7
ZnO,CO₂			ZnO,Fe₂O₃ ZnO,Al₂O₃	Cu₂S† ZnS	Cu₂O ZnO	Ca Zn	Copper. Zinc.	Cu₂O ZnO		CuO ZnO				32 32	31.6B 32.5Erd.	n= 7 n= 7
		SrO,CO₂						Zirconium.		Zr₂O₃					34	33.6B	n= 8
								Strontium.	SrO		SrO₃				44	43.8	n=10
								Lanthanum. Cerium.	LaO CeO	Ce₂O₃	LaO₃				48 48	47 47.3M	n=11 n=11
	(Ir,Rh)O₃							Rhodium. Ruthenium.	RO RuO	R₂O₃ Ru₂O₃	R₂O₄	RuO₃	RuO₂†		52 52	52.1B 52.1B	n=12 n=12
						Pa		Palladium.	PdO		PdO₃				54	53.3	n=13
					Cd₂O	Cd		Cadmium.	CdO						56	56	n=13
		SnO₃	KCl,SnCl₂			Sn		Tin.	SnO	Sn₂O₃	SnO₃				58	58	n=14
			UrO,Ur₂O₃					Thorium. Uranium.	ThO UrO	Ur₂O₃	Ur₂O₄				60 60	59.6 60	n=14 n=14
	(Ir,Rh)O₃	BaO,CO₂					Ir	Barium. Iridium.	BaO IrO	Ir₂O₃	BaO₃ IrO₂	IrO₃			68 98	68.5 98.5B	n=16 n=24
		KCl,IrCl₂ KCl,OsCl₂ KCl,PtCl₂					Pt	Osmium. Platinum.	OsO PtO	Os₂O₃†	OsO₂ PtO₂	PtO₃	OsO₄		98 98	99.4B 98.5B	n=24 n=24
		HgSe			Hg₂O	Hg		Mercury.	Hg₂O		HgO				100	100	n=24
PbO,CO₂				PbSe PbS		Pb		Lead.	Pb₂O		PbO	PbO₃			104	103.7	n=25
				AgSe AgS		Ag		Silver.	Ag₂O	AgO					108	108.1	n=26
						Au		Gold.		AuO		AuO₃			198	197	n=49

THE THREE SERIES.

1 + n3.

ISOMORPHS.		HOMOLOGUES.		ATOMIC WEIGHTS.		
3	1			Theo.	Observed.	n
		Hydrogen.	H₂O	1	1	n= 0
	LiCl	Lithium.	LiO	13	13	n= 4
NaO,SO₂	NaCl	Sodium.	NaO	46	46	n=15
	KCl	Potassium.	KO	79	78.4	n=26

AFFILIATIONS.

AgO,SO₂		Silver.	AgO	217	216.2	n=32